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Information Product Quality in Network Centric Operations

OPERATIONS RESEARCH CENTER OF EXCELLENCE
TECHNICAL REPORT DSE-TR-0516
DTIC #: ADA435046

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Abstract

This study introduces a pragmatic methodology for examining the effectiveness of decision support information systems for Network Centric Operations based on the concept of manufacturing information products. We first develop the definitions and framework for this manufacturing environment, establishing a connection with previous research and extending it into a value-focused domain. We then apply this framework to elements extracted from two recent case studies involving US Forces focused on validating the tenets of Network Centric Warfare, illustrating its unique ability to identify systems level concerns overlooked previously. Lastly, we extend our concern for the reliability of information products, showing how this both complements a quality analysis and, taken together, prescribes a methodology for creating effective information-based decision support tools.

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Keywords: Information Quality, Network Centric Operations, Systems Thinking, Information Reliability, Value-focused Thinking.

1. Introduction

If one is willing to believe that devices, personnel, and systems deployed and operational on the modern battlefield are perfect and that users get exactly what the information they want, when they want it, and in the form they need it from such systems, then there is no practical reason to be concerned with information quality or information reliability. Believing thus is ill advised, however. Military consumers of modern information have by-and-large woken to the realization that

> …information abundance does not necessarily give us certainty. Sometimes it can lead to errors in decision-making with undesirable outcomes due to either overwhelming and confusing situations, or a sense of overconfidence leading to improper information use. The former situation can be an outcome of the limited capacity of the human mind in some situations to deal with the complexity and information abundance; whereas the latter can be attributed to a higher order of ignorance, called the ignorance of self-ignorance. [18]

With military information systems, our concern principally lies with the latter situation, believing as we do that a first line of defense against uncertainty lies in examining military information systems from a multitude of perspectives with the goal of developing a complementary understanding of system capabilities and limitations. The conceptual framework introduced by Perry et al. [23], whose structured perspective on information quality under the auspices of exploring information superiority, is one such valuable

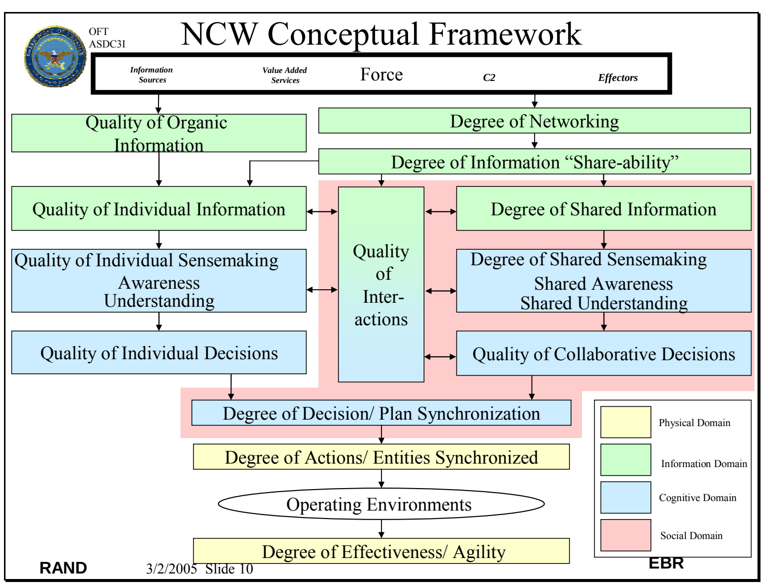

Figure 1. Signori et al.'s NCOCF

perspective, having led to what is currently known as the Network Centric Operations Conceptual Framework (Figure 1). Portions of what we explore herein represent refinements and extensions of a subset of their constructs. In particular, we are directly concerned with issues underlying the quality of organic and individual information and the appropriate structures and models that should be in-place to achieve high levels of this quality.

Our intention is to complement their work with a concept that supports the design and analysis of decision support products, in particular common operating pictures (COP), and uncovers valuable insights worth incorporating into our considerations of system design as well. Our belief is that for any decision support information system deployed in a Network Centric Operations context, a comprehensive systems design addressing quality, reliability, and maintainability of information products should be conducted. Without such design considerations, successful support of critical operational elements engaged in complex operating conditions is left to ad hoc innovation, serendipity, and hope; which is not a strategy for success.

1.1 Why a product manufacturing focus?

Managers of decision support information systems deployed in support of NCO have a choice. They can either view information as a byproduct of the system or event, or as a product. Wang et al. [29] propose five common factors one can apply to determine which approach has been adopted by an organization. Table 1 shows an application of these factors in consideration of NCO systems.

	Information as a Product	**Information as a By-product**
What is managed?	➢ Information product ➢ Information Product Life Cycle ➢ Information manufacturing processes	➢ Hardware and software ➢ Systems life cycle
How is it managed?	➢ Integrated cross-functional approach ➢ Supply chain basis encompassing information suppliers, manufacturers, and end users	➢ Integrate stovepipe systems ➢ Control of individual components ➢ Cost controls
Why is it managed?	➢ Deliver quality information products to end users with high service reliability	➢ Implement quality hardware and software systems with high system reliability
What is success?	➢ Quality information products continuously delivered over the product life cycle with high service reliability	➢ The system works according to required specifications ➢ No bugs ➢ Short-term, “sustain” perspective
Who manages it?	➢ CIO ➢ Information product managers	➢ CIO ➢ IT director, database and system administrators

Table 1. Five factors to determine an organization’s approach to managing information.

One way of understanding the difference being described has to do with *focus*. When information

is viewed as a by-product, the management focus is on keeping critical systems operating in support of the mission. The assumption is that if the system is doing what it is expected to be doing, i.e. it is running, it has not been compromised, and the intended end users and input sources are connected as planned, then the information flowing on the system will necessarily be acceptable. This is not a naïve or uninformed focus; its attention is merely not on the entity that is actually moving from source to end user.

Conversely, when the focus is on the entity itself and information is viewed as a product, in particular a product that is intentionally manufactured by a system, a host of new concerns arise that exist on an altogether different conceptual layer of the system. The activities, or *processes*, that exist in support of this layer are at least as critical to mission success as the physical system layer.

The five factors in Table 1 serve as a useful diagnostic for any organization wishing to understand how they treat information. Additionally, an organization can easily apply a very simple assessment to determine if there is an immediate need to shift their management focus onto the flowing entity:

> *If all hardware and software systems are successfully working as described in Table 1, yet end users are still employing ad hoc "work-arounds" to the formal system processes in order to obtain information they need to accomplish their mission, then management must shift their focus onto information as a product to improve information quality levels.*

The first advocates for a comprehensive information product manufacturing framework for organizations to manage their data and information handling processes was Ballou et al. [31]. Their approach is one closely linked with data quality management in the sense that their framework provided a methodology for tracking data units from source to inclusion in a final information product delivered to an end user. Two effective quantitative measures for the *timeliness* criteria of information quality were introduced in their work: currency and volatility, both of which become important elements in our approach as well, although not taken together in this manner.

Our approach assumes a different perspective, preferring to remain at a slightly higher level of abstraction for pragmatic reasons related to systems design which we explain later. For example, they define information manufacturing as the process that transforms a set of data units into information products, whereas we incorporate the underlying product *purpose* into our definition. Additionally, because our concerns extend into the lifecycle of dynamic information products, we must necessarily be concerned with structuring service reliability, information reliability, and maintainability of information products into our framework as well as quality concerns.

2. Placement within a systems modeling spectrum

The term *system* originates from the Greek *systema* that means an organized whole. The term *system science* is usually associated with observations, identification, description, experimental investigation, and theoretical modeling and explanations that are associated with natural phenomena in fields [18]. More often than not, adopting a systems perspective on collections of interacting elements illuminates holistic qualities easily overlooked by invoking a Western *reductionism* [41] viewpoint in which the "whole is the sum of its parts" [40]. *Holism* assumes that the "whole is greater than the sum of its parts." For systems of interacting components, a holistic philosophy contends that there exists emergent behavior in tandem activity that is not present when components are acting alone. For NCO systems, effects such as compressed parallel mission planning activities afforded by digital networked communications is an example of emergent behavior of this type. These effects are commonly referred to as *synergistic* effects. The philosophy of holism supports how we conceptualize information as an entity.

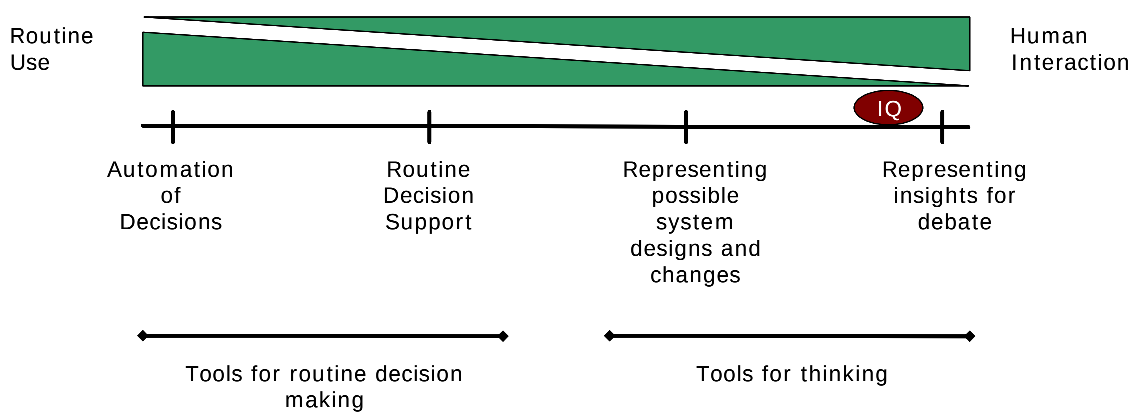

Figure 2. Placement of study within a systems modeling spectrum [26].

Definition. A *systems perspective* of an information product is as a collection of individual components whose support to purpose is greater as an assembled manufactured information product than any of the individual components could provide when taken individually.

We view an information product as a system in a manner distinct from the technological system that houses and disseminates this product. Stated another way using a concrete example: a properly manufactured COP (information product) provides more direct support for effective decision-making than any of the individual elements comprising the COP could do when taken alone. The whole is

greater than the sum of its parts.

We also adopt a *construction* or *compositional emergence* epistemic position [42] with regards to designing information products for manufacturing. This is a form of microdeterminism in which the parts and their interactions comprise the structure of the larger system. This implies that before a cohesive information product can be designed and manufactured, one has to first understand how the components of this product relate to the unifying purpose individually, the type of inter-component support relationships they exhibit (positive, neutral, negative), and what type of holistic behavior they should exhibit when assembled properly.

Figure 2 illustrates the placement of this study and its content within the spectrum of possible systems modeling efforts. At one end of the spectrum are models that are designed for routine decision making. These models typically replace or supplant specific functions previously performed by human decision-makers. Good examples are the classification and identification algorithms imbedded in unattended ground sensor cluster gateway nodes [43]. They routinely 'decide' on what they are detecting using feature set-based mathematical models built into their software.

At the other end of the spectrum are models whose purpose are to enhance human understanding; hence, tools for thinking. They provide a lens through which decision-makers can view complex and challenging problems or the environments that contain these problems. The cognitive framework reflected in a 'systems perspective' is a classic example of one such model.

This study resides at this end of the spectrum as well, as indicated in Figure 2. It proposes a model for thinking about information that is used to support decision-making on the battlefield: as an intentionally manufactured information product that is the result of carefully structured and controlled manufacturing processes.

2.1 Systems placement of the manufacturing metaphor

The concept of an information manufacturing process aligns with metaphors principally drawn from cybernetics that emphasize active learning rather than an alternative passive adaptability that characterizes metaphors that see the information network and the humans interacting with it as an organism [20]. Thus, attention is focused on decision-making, information processing and control. Underlying the information manufacturing metaphor is an assumption that the organization has decided on a product's unifying purpose and is challenged to design complex systems to respond to surrounding turbulent environments the product finds itself placed within upon completion and distribution.

While an information manufacturing system can be conveniently represented as a simple flow diagram, one recognizes that a large degree of control over the product is decentralized because

induced change is sufficiently complex to preclude it from being handled exclusively at the top of the organization. The organization must manage single-loop learning, correcting deviations from prescribed quality criteria goals. At the same time, it must also be capable of double-loop learning, changing the nature of its purposes if these become unattainable as the environment shifts [21]. Military operations have a natural affinity to this type of metaphor as the requirement for active learning is a prerequisite for successful leaders, units, and missions.

The information manufacturing metaphor does not address the motivation of individuals acting as imbedded elements of the process, to conflicting elements of interactions, nor how fundamental purposes are actually derived. These shortcomings do not detract from the effectiveness of the metaphor in getting at information quality in a military setting because of the homogeneous nature of these elements in military operations. Individual motivations are united to achieve the mission, conflicts are subservient to command, and purposes are clearly reflected in mission intent.

3. The nature of data, information, and knowledge

Data is raw, unstructured bits of quantitative and/or qualitative facts. For example, the number "210" and the words 'fast' and "agitated" are just facts. Structured data by purposeful design or in response to system user queries is information. Structuring the three pieces of data in response to the user queries, "How heavy is the boxer?", "Is he fast or slow?", and "What is his demeanor?" changes the three bits of data to contextualized formatted data, or information. When merged with the user's experience of boxing opponents fitting these characteristics, the information becomes actionable knowledge.

Researchers [18] posit that knowledge is created at three distinct levels: cognitive, knowledge that can be acquired by the senses; knowledge based on correct reasoning from hypotheses; and belief followed by conjecture, in which knowledge is based on inference, prediction, or theorization based on incomplete or reliable[1]. For information products, the various forms of data serve as input resource streams to the process of manufacturing, as do labor, materials, time and other typical manufacturing elements.

Data quality efforts, while sharing some of the characteristics of information quality, seek to reduce errors, meet specifications, and somewhat in common with a service reliability standpoint, increase customer satisfaction. In contrast, information quality has the goal of improving the usefulness and validity of information, in this case, information products. It is inherently a system-level focus, one that assumes a posture of insuring fundamental quality characteristics are explicitly considered during

[1] We use the term 'reliable' here in a sense consistent with *reliability theory of knowledge* [19].

the creation, deployment, and maintenance of both information products and their associated manufacturing processes in a network.

Information serves purposes that are determined by an individual user or groups of homogenous users sharing common purposes. In general, information communicates answers to questions and statements about situations and facts. When information is created and shared over digital networks for the purpose of decision making, we refer to these digital networks as decision support information systems (DSIS). Sensor-to-shooter targeting systems are an example of one subset of DSIS in which a fire/no fire decision must inevitably be made.

The domain of knowledge management is principally concerned with recording, storing, and making readily accessible to appropriate users vital knowledge elements that sustain the core of operational identity of an organization. The resulting knowledge base consists of both knowledge about key processes (know how) and knowledge within these processes (know-what). Information managers concern themselves with the proper selection, structuring, and delivery of information products to users in response to needs. Data managers focus on the acquisition, storage, and transmission of raw data as an input resource to information products, principally those used in support of decision making. Issues of security are shared in all three layers. Information quality underscores the knowledge base.

In order to assess and possibly improve the quality of information in NCO systems, focus should be applied to both the content and structure of the information products [6], the manufacturing processes (manipulation, service to end users), and the system infrastructure. The latter of these remains a concern of computer science and information technology specialists and will not be directly addressed in this paper.

3.1 The value of information

In this study, our interest is not in assessing or managing the value of information to network centric organizations. However, it is worthwhile to briefly discuss several important results in this area as they pertain to information so that the distinction between quality and value is apparent.

Over time, researchers have proposed analytical approaches for assessing the value of information, which are quite apart from the notion of quality, reliability, or maintainability of information products. The most predominant concept is an extension of the thermodynamics principle involving *entropy*.

Entropy is a property of all thermodynamic systems and is represented by the following equation:

$$\Delta S \geq \frac{\delta Q}{T},$$

where ΔS is the change in entropy, δQ is the change in heat energy and T is some constant

temperature. Whenever heat enters or leaves a system, entropy changes. Notice that the change in entropy is positive for every interaction, meaning that entropy for part of a thermodynamic system can be reduced, but entropy as a whole for the system increases. The only way that entropy can be reduced overall is by putting energy into a system. It is this property that points to an analogy with uncertainty – it seems to increase of its own volition unless something is actively done to reduce it (energy).

Brillouin [47] introduced Schrodinger's idea of negative entropy, or *negentropy*, replacing S with an expression of opposite sign $N = - S$, which behaves more intuitively than entropy, steadily decreasing over time [48]. This concept provided a link with both information theory, relating uncertainty to entropy and information to negentropy. As more information (quantity) is gained about a system, both uncertainty and entropy decrease.

The seminal work by Shannon [32] and its associated derivatives directly exploit this association but intentionally exclude considerations of the semantic meaning of the message. Shannon's concept of *mutual information*, which characterizes information value in terms of entropy functions, was originally associated with analyzing the source of the message to discover what capacity is required in a communications channel to transmit all the messages that the source provides, and then extended to consider information. This extension is based on an assumption that the uncertainty regarding any variable Z characterized by a probability distribution $f(z)$ can be represented by the entropy function:

$$H(Z) = -\sum_{Z} f(z) \log f(z)$$

An example is helpful [49]. Suppose that we were interested in some target variable T whose value has some amount of total uncertainty $H(T)$ associated with it. Let X represent the total possible set of information that we could acquire to help resolve this uncertainty. Then, the residual uncertainty regarding the true value of T, given that we acquire x, is then written as an entropy expression

$$H(T \mid x) = -\sum_{t} f(t \mid x) \log f(t \mid x),$$

The average residual uncertainty in T, summed over all possible information we could acquire x can then be written as

$$\begin{aligned} H(T \mid X) &= \sum_{x} H(T \mid x) f(x) \\ &= -\sum_{x} \sum_{t} f(t,x) \log \frac{f(t,x)}{f(t) f(x)} \end{aligned}$$

The total uncertainty reducing potential of X, called Shannon's mutual information, is given by

$$I(T \mid X) = H(T) - H(T \mid X)$$

There are two main limitations with this approach. First is that there is no notion of the relevance to the task at hand [36]. Viewing two messages from distinct sources as equivalent because they have the same entropy value misses the point that when they originate in different situations their value could be different. Moreover, representing the loss of information in terms of entropy functions fail to directly accommodate notions of quality with respect to information products.

Secondly, Shannon's measure does not reflect ordering or scale information relative to the values that a variable can take on. Consequently, while it does measure the cost of resolving uncertainty, it cannot, for example, differentiate between the cost of obtaining critical information and non-critical information in doing so.

Overall, this value focus concentrates on the process of communicating and obtaining information and the associated loss or gain in value as a result, a task we propose is more naturally assigned to information assurance efforts than quality assessments. As a side note, Barr and Sherrill [33] extended a portion of this earlier work to encompass tactical information. Again, however, the notion of assessing, maintaining and sustaining information quality are not present in their approach.

Glazer [34] advanced the discussion of information value to a more systems level approach, characterizing behavioral priorities in information-intensive firms that lead to real competitive advantage. His underlying point is one that we take to heart in this study as well: information-intensive organizations (transformed US Forces) see Information Technology (IT) as the enabler of growth in the production and distribution of information. The output of these technological systems, *the information itself*, carries value. His approach has received a small amount criticism because it ignores the value added element associated with the technology [35].

Most importantly for our purposes, he argues that successful organizations have gone beyond a focus on the technology to view the information itself as the organization's primary strategic asset and have directed management to focus their attention on this key variable. Using a product for purchase transaction as the base unit of analyses, he identified three general components of information value:

1. Given the information, revenues from subsequent transactions are greater than they otherwise would be;
2. Given the information, costs of subsequent transactions are lower than they otherwise would be; and,
3. The information itself is marketed and sold to other firms.

The firms he examines have a good deal in common with the organizations envisioned for a transformed US Force. Defining a transaction as an exchange of information product(s) that occurs between the information manufacturing system's application layer and the end user, we can translate

and restate his three general components of value for use with NCO systems

Definition. For NCO systems, indications of information product value fall into three assessment components:

1. Given the information product, mission effectiveness and efficiency is greater than it otherwise would be;
2. Given the information product, mission costs (resources, including loss of life) are lower than they otherwise would be; and,
3. The information products, or appropriately tailored versions of them, are marketed and shared with multi-national forces in a manner that illuminates a growing dependency on these products by these forces.

While the first two valuation components are part of the existing NCOCF thought processes, the third is new. It recognizes that in a multi-national force setting, the *information products have value apart from the missions they are designed to support*.

NCW products such as case studies, short courses, and information created within the social networks of the Transformation Chair network are products of this type. The growing demand for these products outside of the context within which they were intended to serve (e.g., capturing lessons learned and observations of network-enabled forces during the Iraq War) demonstrate the existence of such a market.

The choice of an *object of valuation* appears to some researchers [35] to be a prerequisite for the definition of the value of information. Arising principally in economics ([37], [38], [39]), this concept gave birth to the notion of an *information commodity*. This provided a conceptual bridge between the general abstraction of information and the valuation of a specific manifestation of information: a product. And once an object can be validly conceptualized as a product, all of the associated metaphors and modeling issues associated with manufacturing products become fair game to explore.

Separating the *furnishing* of information from the *valuation* of information in these same studies proved another useful advance that we build upon in a related study [44] in which we examine the concept of service reliability as it relates to information product delivery. Separating product quality from service reliability is an important distinction to make because it effectively assesses a decision support information system (DSIS) from the end user perspective rather than the system design and management viewpoint.

4. Information product manufacturing perspective

Much of the previous work associated with information quality focuses exclusively on data quality ([2], [6]) or attempts to frame a general notion of information characteristics that, while important to theoreticians, is lacking in its ability to provide guidance as to how one might go about imbuing these characteristics into specific user required products. Data quality is a directly measurable, low-level construct. It is relatively easy to structure metrics against criteria of data quality since the objects in data bases can be tracked back to actual data generation sources and checked directly for error presence, missing elements, or other similar quality indicators while they reside in storage.

The first such efforts immerged from the field of accounting ([25], [27]). These were motivated over concerns about the integrity of the data being used for both corporate performance analysis and actuarial assessments of insurance instruments. Since that time, pragmatic differentiations between data, information, knowledge, and wisdom have come to pass that have afforded researchers the opportunity to fine tune there conceptual representations [18].

Information, being a higher-level abstract object, is a good deal more challenging to assess in any of the three areas noted: quality, reliability, and maintainability. Doing so requires careful consideration. Although many of the concepts associated with classical theory related to these areas may at first glance appear to directly apply, we are cognizant of the words of Cushing [24], one of the earliest pioneers interested in applying reliability measures to data systems:

> *"The concepts of reliability and maintainability are both borrowed from the field of engineering for application in a context far removed from that envisioned by their creators. There is no assurance that such borrowed concepts will be meaningful in a new environment, and it is therefore incumbent upon the borrower to demonstrate the connection between the concept and its intended application."*

Pinning our focus to the notion of an information product is a practical choice that helps ameliorate this challenge. It frames information quality as relative to something in particular. Constructing a framework within which one can pragmatically discuss, design, analyze and adapt such information products is empowering and particularly appropriate for Network Centric systems.

Information is, at its essence, an abstract object characterizing anything that comes to us by way of our senses that through cognitive processes, more specifically a dialectical process [18], informs us. It defines both our interface with existence and our conditioned way of understanding this existence. We shape information, trade it, hoard it, accumulate it, destroy it, and store it. At the right place in

the right form at the right time, we find it immeasurably valuable. At the right place in the right form at the wrong time, it is utterly useless to us.

4.1 Manufacturing Components Defined

Military professionals in decision making roles have long recognized information's potential to turn the tide of battle or at least afford an operational advantage when its possession represents an asymmetric advantage to friendly forces. The military classification system is testament to this assertion. If information – whatever it may be – can be owned and valued, it can be a commodity. Rather than speaking of information as a commodity per se, we chose to call it an *information product*.

Definition. An *information product* is an intentionally constructed assemblage of static and dynamic components bound together by a single cohesive purpose for an audience whose needs for information are known and well-understood.

While seemingly broad in its definition, it nonetheless sufficiently bounds the concept so that one can properly access notions of information quality and service reliability. Yet, it remains general enough to apply to all forms of military information used in tactical, operational, and strategic decision-making.

Definition. The organized collection of activities and dynamic flow of resources that results in the creation of an information product is an *information manufacturing process.*

Definition. An information system that produces predefined information products is an *information manufacturing system.*

Our appeal to the concept of viewing the creation and dissemination of information as manufacturing information products extends previous work in this area ([6], [34]). Believing that there is value in modeling and analyzing information apart from the hardware components carrying it, a manufacturing framework serves a variety of complementary purposes.

First, since the activity of manufacturing is familiar to most, translating and applying appropriate metaphors and concepts to information is both natural and appealing because the abstraction is simply accommodated. We do not go so far as to suggest that *all* quality-related manufacturing theory and

practices validly translate to NCO information systems. However, we strongly believe that under the correct structural framing a critical subset do, and those that do offer an opportunity to revise, restate, and extend elements of the NCOCF. Moreover, we note that fundamental spatial arrangements of manufacturing facilities nicely decompose and organize the three major elements: data, information products, and knowledge into an appropriate hierarchy with regards to military information systems.

Secondly, thinking about information systems in this manner shines a spotlight on critical systems issues concerning the manufacturing processes themselves. For example, where should quality blocks (to be explained) be placed in the process? What resource acquisition policies should be in effect? What skill sets are required by the individuals involved in the manufacturing processes? How are these to be maintained knowing that rotation and/or attrition will occur among these personnel? What raw data materials should go into the product? How should the product's quality levels be maintained? Which end user requirements are fixed and which evolve? Who should create the product's dynamic and static components? What functions should these perform? Which product presentation form is most effective in supporting the purpose? Inevitably, issues such as these are tied to quality considerations.

Interestingly, even more subtle issues arise as second order effects in a manufacturing context. In particular, we note that the world view represented in the manufactured product has an impact on its perceived value to the user. Does it ultimately represent the concerns of the manufacturer, the end user, or both? And, if the pool of end users changes over time as it most assuredly does, can the information manufacturing process evolve to accommodate and align with the needs of the changing user pool as well? Or must end users develop work-around processes to maintain the product's usefulness? How will the manufacturing facility identify the emergence of quality degradation indicators? What are these indicators?

A manufacturing perspective naturally motivates design concerns that focus on the quality of specific content elements. For information products, we identify nine characteristics of quality information that should be present in every product released to an end user. The extent to which each of these characteristics is present and exactly how a designer should measure each one of them is still an open question, although we investigate a select number of options in this paper.

Starting with the original eight elements of information quality stated in the NCOCF, Perry et al. [23] carefully construct one methodology for doing this for the notion of information in general as it applies to the construction of what they refer to as the common relevant operating picture (CROP). We take the process further by both widening the span of consideration to quality, maintainability, and reliability in this study. The information product manufacturing perspective enables us to tie these three areas together in a cohesive manner, thereby beginning to construct a robust and novel

concept of information reliability, an on-going effort whose basic elements are presented in the final section of this paper.

4.2 Dynamic Quality Growth Over Time

While it is recognizably important to comprehend the concept of information, focusing on the manufacturing of information products creates actionable criteria for quality that can guide the creation of specific product features and the processes associated with creating these features.

Treating information as a product requires four basic principles be followed [29]:

1. Understand the end user's information needs.
2. Manage information as a product of a well-defined production process.
3. Manage information as a product with a defined life cycle.
4. Appoint an information product manager to manage the information manufacturing processes and resulting product.

Most of what follows explores principles 2 - 3 in detail. The fourth principle follows directly from this exploration. The first principle requires that system designers clearly understand what an end user needs with regards to information supporting decision-making, when it will be needed, and in what form it is needed. These are obvious. Less obvious are the converse of this principle: we must also understand what an end user does *not* need, when the product or some subset of its components are *not* needed, and in what form it should *not* be delivered. It is this complementary principle that offers some respite to the logjam of information overload because it suggests that an end user may not need everything all-the-time present in their information products. This is very important in what follows.

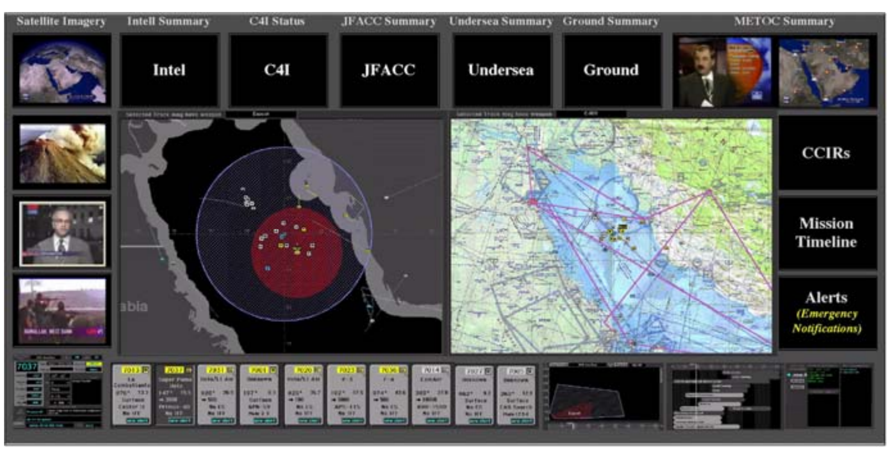

Figure 3. Command 21 Knowledge Wall conceptual design (source: SPAWAR, 1999).

Information overload can be diagnosed by observing that the end user cannot productively use the

quantity of information within the time scale available. The right amount of information is a cautious construct that illustrates that the criteria of *comprehensiveness* and *completeness* with regard to information are relative terms. The effectiveness of a system can consequently be assessed by measuring the "knowing – doing gap" [9].

We posit that this insight presents an opportunity to design dynamic information products whose quality levels intentionally fluctuate to meet target levels of quality criteria at various scheduled times during their life cycle; a just-in-time strategy with appropriate redundancy in-place.

For clarity on this point, we are not simply proposing that products are timed for optimal delivery to the end user, although this certainly may be the case. We are proposing that a single information product can be decomposed into interrelated component parts not all of which need to be at high levels of quality and reliability criteria at the same time. Figure 3 illustrates the varied number of interrelated components that can and do appear on a single information product. As we later describe, depending on the predetermined, time-dependent needs of the end user for quality, it is possible to schedule the delivery of quality at various levels to maximize the effectiveness of the information product as it relates to the purpose for which it was created, and to minimize information overload by *not* providing excessively high quality components when they are not needed.

This scheduled variability in quality criteria levels corresponds to a "Big-Q" – "Little-q" definitions of quality.

Definition. A Big-Q notion of information quality recognizes that there are a core set of criteria that are required of all information products prior to acceptance by an end user.

Definition. A Little-q notion of information quality establishes the degree to which an information product meets or satisfies its underlying Big-Q quality criteria.

For a host of manufactured products, these two concepts become a management concern at the point of release of the product. The typical assumption at release is that quality monotonically non-increases past this point. Most attempts at quantifying quality criteria for information in fact assume constant deterioration over time, independent of context, a point over which we take exception.

What we are proposing is that a single information product can have variable Little-q levels of quality criteria over its planned life cycle. The manufacturing process in-place should be flexible, adaptable, and responsive enough to be able to accommodate this planned variability through appropriate quality controls inserted into the progression of manufacturing activities.

This focus on manufacturing information products inherently assumes a systems perspective ([21], [26]) that enables one to consider information as an aggregate assemblage of components whose collective behavior or message as a system is not present at the individual component level. An

information product is properly viewed *as a system* under a specific framework that we introduce in what follows. Understanding the nature of information products enhances the suite of modeling tools available to NCO systems designers to create, distribute, protect, and maintain these products over their usable lifetime.

From a systems perspective, adopting the framework of information product manufacturing creates natural allegorical structures against which designers can innovate, extract critical ingredients, and consider time-evolutionary effects such as service erosion, reliability degradation, and maintenance of quality.

Furthermore, as will be explained, an information product manufacturing framework appears to exclusively enable one to link information products such as a common operating picture (COP) to *purpose*, a key link if one wishes to decide which information components should be included or excluded based on considerations of inference chains [28]. It then becomes possible to examine the reliability of the COP in terms of either goodness, or *risk-to-use* (RTU) based on the degree of inferential support the purpose-networked elements provide at any point in the lifetime of the product. This particular dimension of this study is currently under investigation by the authors.

4.3 Dynamic Information Products and Quality

Battlespace factors exogenous to information systems, such as weather, soldier stress, cognitive error, and weapons effects, compound the challenges for decision support information systems to operate as idealized in their design. In any framework addressing quality, reliability, and maintainability, it is prudent to view the products of such systems as dynamic as well as static, taking into account the critical components, their functions, and the manufacturing processes associated with these products.

A reasonable systems scientist would suspect that some information quality criteria levels would naturally change continuously over time while others may make discontinuous jumps upwards or downwards. We likewise suspect there are some criteria of quality that are relatively time-invariant, yielding to other yet-to-be-determined influencing factors instead. Failing to understand how these criteria coexist, how they dynamically relate, and what binds them together into a unified product, runs the risk of designing, developing, and distributing products to operational units that are, at best, approximations of the products they could have or should have been. Resolving this suspicion is an open question to-date.

Considering information product components and manufacturing processes in a dynamic fashion likewise suggests an interesting possibility we mentioned earlier: that information products can be designed for *information quality variability* over time in a manner somewhat akin to system reliability

growth in more traditional system reliability design [3]. This would imply that processes can be formalized and inculcated into these information systems that achieve and maintain varying appropriate target levels of agreed upon quality criteria well past the point of release to the end user.

In fact, it is natural to consider that there would be a subset of manufacturing activities that would not even begin until a considerable time after the initial product release to the end user has transpired. At an appropriate time, these activities would create or engage specific sub-components of the information product to provide real time quality target level achievement as required. An example of this concept that comes to mine would be the intentional delay of a real time, high resolution Preditor video feed until a predetermined time for its need is reached. Providing this feed earlier than needed might distract the user and most certainly would marginally contribute to information overload. Providing this feed later than needed by the user degrades both the information quality and service reliability.

As an example, consider the Special Operations Force (SOF) planning sequence introduced in the Naval Special Warfare Group-1 case study [30] shown in Figure 4. The overall mission sequence undergoes a series of distinct activities culminating in a successful mission end state. Table 2 illustrates a hypothetical dynamic scheduling of product element sequence deployments in direct support of mission planning and execution. Table 3 then shows the information product quality criteria requirements aligned with these same product element deployments.

In this hypothetical example, the levels of quality criteria are specified relative to a SEAL team's identified operational needs over time. Identifying these requirements should be part of the early stages in mission planning, well in advance of an operation's start point, and inculcated into the manufacturing processes in-place that create the specific SEAL team's information products.

A highlight noted in the NSWG-1 case study underscores the need for manufacturing processes to be adaptable enough to be able to effectively respond to ad hoc requirements outside of the schedule as well. In the NSWG-1 case study, this was noted as the ability of the MSC to tailor the information products to

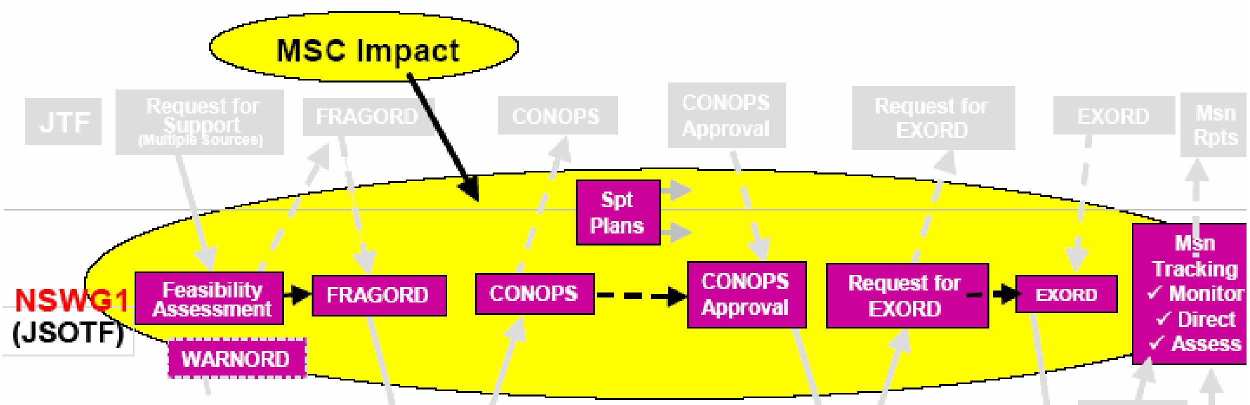

Figure 4. SOF planning sequence extract (source: NSWG-1 Case Study, Booz Allen Hamilton).

meet the evolving needs of the SEAL teams. Their manufacturing process, largely by serendipity, was capable of effectively responding to changing user requirements for both format and content. In addition to what was noted therein, it is also critically important to sustain the purpose of the information product as well: to support accurate inference concerning variable, vague, unknown, and possibly random elements of the battlespace environment

The content, functionality, and structure are subsequently tailored in their delivery to accommodate these quality requirements. This approach would then be applied to the design of individual information products, or classes of products in explicit recognition that one could maximize the effectiveness of an information product by aligning its *evolution* with that of the environment into which it is to reside. This is a transformation concept, and an example of designing an information product for quality *growth*, a natural capability of dynamic digital information products. One cannot help but recognize a need for systems designers to assume an information product focus in order to structure this type of dynamic performance.

In comparison to six standard structured systems development models [45], this notion is quite distinct. The goal of a manufacturing process is to insure that the information product has all the required levels of quality at precisely the time they are needed. We simply contend that this should not exclusively be enforced at the point of release to the end user. In this manner, the information product maintains "completeness" throughout its effective life cycle even though some components are present at lower (and higher) levels of quality criteria. The manufacturing is as it was intended to be in order to maximize support the purpose of its existence in the first place.

Sequence Time-Point	Description

τ_0	Initial deployment of information product to user
τ_1	Mission feasibility assessment
τ_2	Support plans
τ_3	EXORD
τ_4	Engagement ROE assessment
τ_5	Objective window open
τ_6	Objective window closed
τ_7	Mission assessment

Table 2. Hypothetical mission-critical information product deployment time points.

Design Quality Criteria	τ_0	τ_1	τ_2	τ_3	τ_4	τ_5	τ_6	τ_7
Completeness	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Conciseness	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.5
Consistency	0.8	1.0	0.8	1.0	1.0	1.0	0.7	0.8
Currency	0.7	0.9	0.9	0.9	1.0	1.0	0.9	1.0
Traceability	0.5	1.0	0.6	0.9	1.0	0.9	0.7	0.8
Comprehensiveness	0.7	1.0	0.8	0.9	1.0	0.9	0.3	1.0
Accuracy	0.7	0.8	0.9	1.0	1.0	1.0	0.7	0.8
Clarity	0.8	0.9	0.6	0.9	1.0	1.0	0.8	1.0

Table 3. Minimum required information product quality criteria levels over the product's mission life cycle.

4.4 Life Cycle Stages

In general, an information product life cycle can be defined as the stages through which information passes from introduction to obsolescence [29]. Based on the concept of quality, we posit four stages characterized by the levels of quality present in the product: creation (introduction), growth, maturity, and decline. The *creation* stage culminates with the levels of quality present upon release to the end user (τ_0).

The *growth* stage recognizes the dynamic nature of information products as described earlier.

During this stage, process managers focus on successfully accomplishing those activities designed to raise or release specific levels of quality criteria in accordance with a life cycle schedule, until the quality levels reach a maximum level in all categories, as illustrated in Table 3 at time τ_4.

The *maturity* stage immediately follows the point of maximum quality. During this stage, process managers progressively shift the focus of their activities to maintain alignment with the schedule, allowing non-critical quality levels to naturally decline or sustain without intervention while committing resources and effort to raising or maintaining high levels of quality in critical criteria.

Finally, the *decline* stage is as it suggests: a period in which the product may or may not undergo re-use or renovation, depending upon its design. Researchers who attempt to capture the life cycle of an information product tend to focus exclusively on creating functional descriptions of what transpires concerning some dimension of measurement on information. Most assume that time is the dominant factor against which the measure of information declines. This may or may not be the case. All assume that decline is inevitable across all quality criteria, a point to which we do not concur.

The decline stage is a period in which process managers are not actively attempting to adjust the quality levels with regards to the product. In a sense, it is a transient period for the information product in which its fundamental quality response to the environment within which it finds itself takes place. Some levels of quality are unaffected, some deteriorate, and some quite possibly improve. Exactly which criteria respond, and in what manner, depend upon the particular structure of the information product and the environmental factors present that are able to affect change.

We note for completeness that not all military information products reach the decline stage. Whether they do or do not is a function of the mission they are deployed to support. In the NSWG-1 case study, once the SEAL teams complete a specific mission, the information products supporting that mission could enter a decline stage on the assumption that the team would be shifting its operations to address new objectives and the old products are no longer needed. Some may never reach the decline stage. These continue to mature, entering re-manufacturing processes that adjust quality criteria levels until their re-use. Digital imagery information products are a good example of this.

What are these processes that need to be managed? Where are they located in the overall information manufacturing system? When should they be performed? What affects do they introduce? Is there a priority ordering of these based on some notion of marginal returns to mission effectiveness? Who should perform them? These are among the myriad of open questions that arise in this context, all of which have answers that contribute significantly to understanding the quality state of an information product.

With this in mind, we proceed to investigate salient issues pertaining to information product

quality in this study with the intention of presenting as complete a framework as possible. A host of issues are still open and we mention these where they occur. These will require further investigation to reach conclusion.

Not surprisingly, managers in knowledge intensive commercial firms have come to realize that "information quality is a decisive competitive factor and that non-quality information can be a crucial cost driver" [2]. For the military, these costs tend to be amplified because of the inclusion of potential loss of life into their mix.

5. Information Manufacturing Representations

DSIS are the type of networks of interest to this study, ones that provide a critical service to some element of military force units that must make decisions affecting missions undertaken on the part of tactical operations. By conceptualizing the various activities that create, format, distribute, and maintain information as a manufacturing process, it is possible to separate concerns over the quality of these products from the quality and reliability of the services these products provide to the users of these DSIS.

Figure 5 provides a representation of DSIS for the case of CTF-50 naval forces case study [53]. In it, both sensor networks and human transmission serve as an entry point for resource streams of primitive data for the ensuing manufacturing processes. For judiciousness in exposition and without loss of generality, we aggregate all such processes at a single point of manufacturing in the diagram.

In practice, it is more the case that various intermediate information products are created to satisfy demands of users throughout the system in addition to the principal target for the final information product(s). These intermediate information products can also be an assemblage of many elements of primitive data and intermediate information products.

To add to the complexity in representing such systems, there also exist manufacturing points in a DSIS that rely on human cognition merged with individual knowledge to modify an existing intermediate product before passing it on through the system. It is possible to classify these manufacturing points as being objective or subjective in nature depending upon whether such points incorporate describable processes that can be readily automated, or complicated analytical processes that further complicate modeling efforts.

At an Analysis Facility, individuals or software applications transform data from the resource streams into information products in concert with predefined rules. These rules run the gamut from simple to complex. For example, a simple transformation rule could define an order in which data of type 1 always precedes data of type 2. Or, the transformation rule could be exceptionally complex,

involving for example, sequential or parallel fusion, image processing and filtering steps, statistical analyses of results, and so on.

The resulting information product is then passed to a Synthesis Facility. The Synthesis Facility assembles the various information product components into a single, cogent information product.

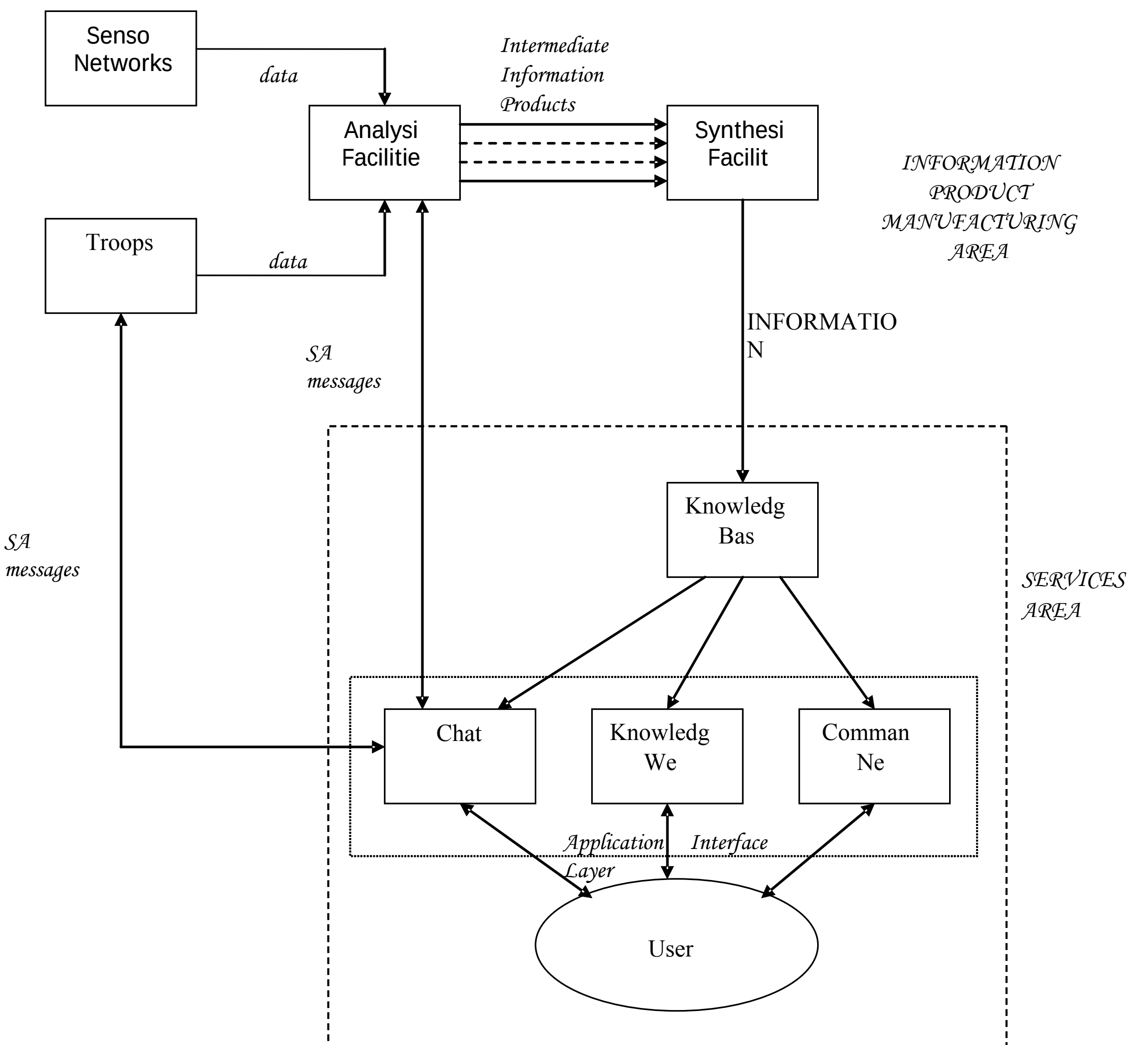

Figure 5. Spatial arrangement for components of information manufacturing in CTF-50.

A truly classic example of a Synthesis Facility is the Mission Support Center (MSC) in San Diego, California, that was created to provide reachback support for NSWG-1 SEAL teams operating in Afghanistan and Iraq. When intelligence analysts are participants in this manufacturing process, it is quite likely that the information components will be integrated with organizational experience, thereby actually creating interpreted information we call knowledge. Practically speaking, we choose

to not explicitly represent a knowledge component apart from an information component because it is difficult for an end user to distinguish between the two. Whether knowledge components can be automatically merged into information products remains an open challenge that we do not address. However, the storage and preservation of knowledge for any organization is an imperative to survival.

Users communicate with the information system through the applications interface layer. The three

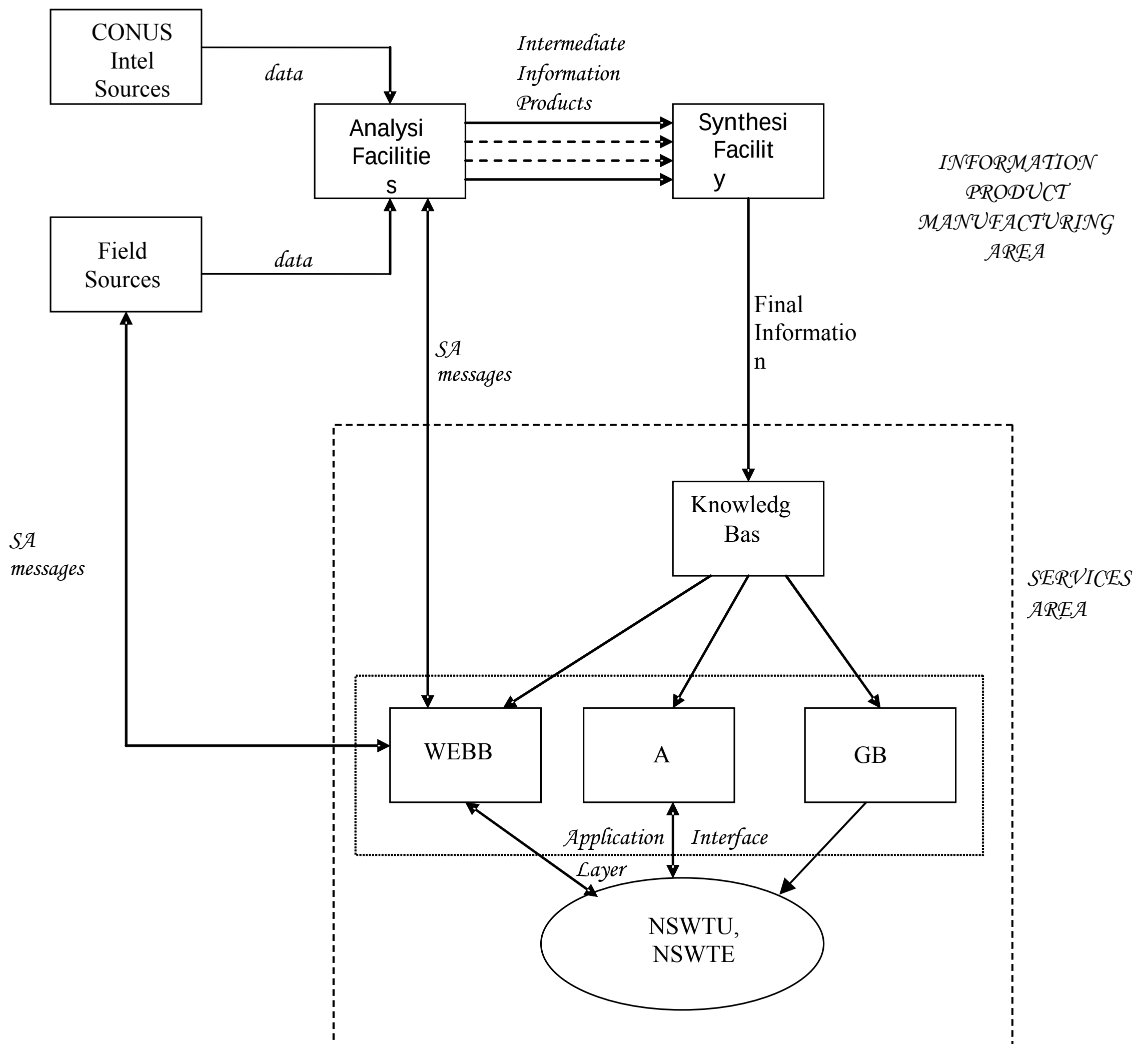

Figure 6. Information product manufacturing for NSWG-1 operations in OEF.

applications in the diagram are so noted because they arise in the CTF-50 case study and are excellent examples of the kinds of interfaces that NCO systems currently exploit. The reliability of the transactions that take place across this interface is what we define as service reliability.

Figure 6 illustrates how the same concept applies to the NSWG-1 use of the Mission Support Center (MSC) during Operation Enduring Freedom [30]. The three major service applications shown

are: A3 (a relational database of tailored intelligence products), WEBBE (a multi-point instant messaging tool with voice-over IP capabilities), and GBS (a broadband satellite downlink that provided for fast transfers of large data files). The MSC is a Synthesis Facility comprised of Analysis Facilities representing each of the seven major intelligence and information resource streams being incorporated into information products: national intelligence agencies, meteorology & oceanographic support, service specific organizations, consolidated

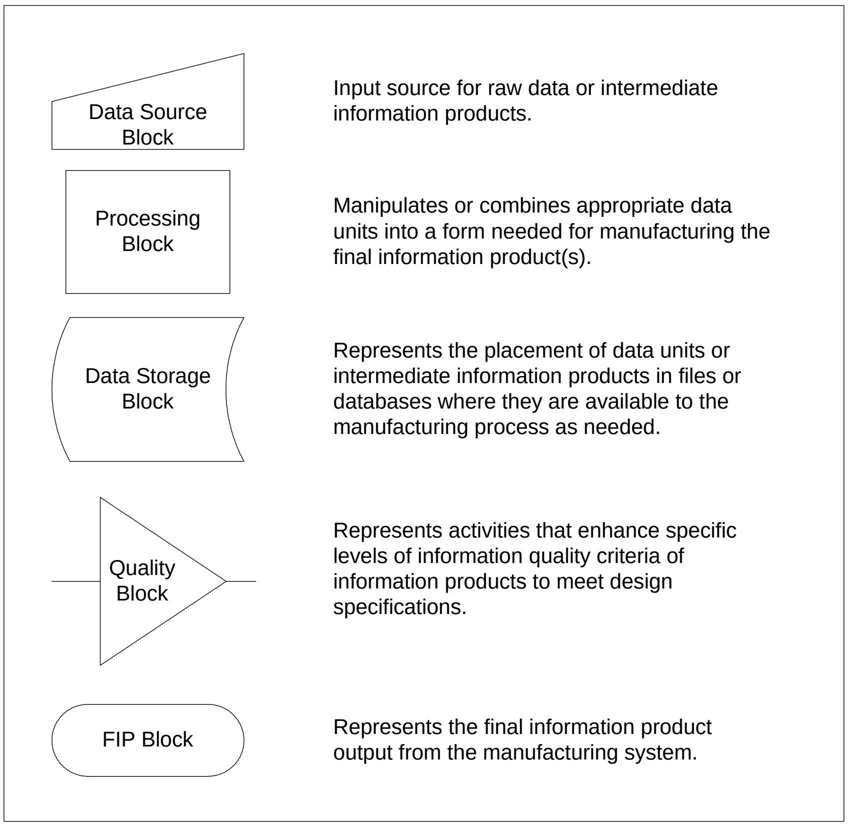

Figure 7. Components of an information manufacturing system.

logistics, theater intelligence agencies, Department of State embassies, and SOCOM/SOCJIC.

The special arrangement of data sources, analysis facilities, and synthesis facilities illustrated in Figures 5 and 6 are high level representations of an information product manufacturing system. A more detailed representation is possible as well using a flow diagram of basic system components proposed by Ballou et al. [31] shown in Figure 7. Once these blocks are linked using the physical flow characteristics of data units (DU) or information units (IU) through the system, a low-level analysis of quality can proceed as the product progresses towards the FIP block.

Figure 8 illustrates a spatial arrangement form that the CIA intelligence resource data stream supporting the MSC could assume. Within the diagram, there are 4 quality blocks (QB) shown. Data

originates from both HUMINT and SIGINT sources in a particular theater of operations. QB1 and QB2 are quality blocks designed to formally review and verify target level of accuracy, currency and traceability of field data prior to it being transmitted into the CIA database. These are examples of feedback controls that target output quantities, adjusting quality levels by direct interaction with the input sources. QB3 is another feedback quality block in-place to maintain the integrity of the database, insuring the completeness and currency of

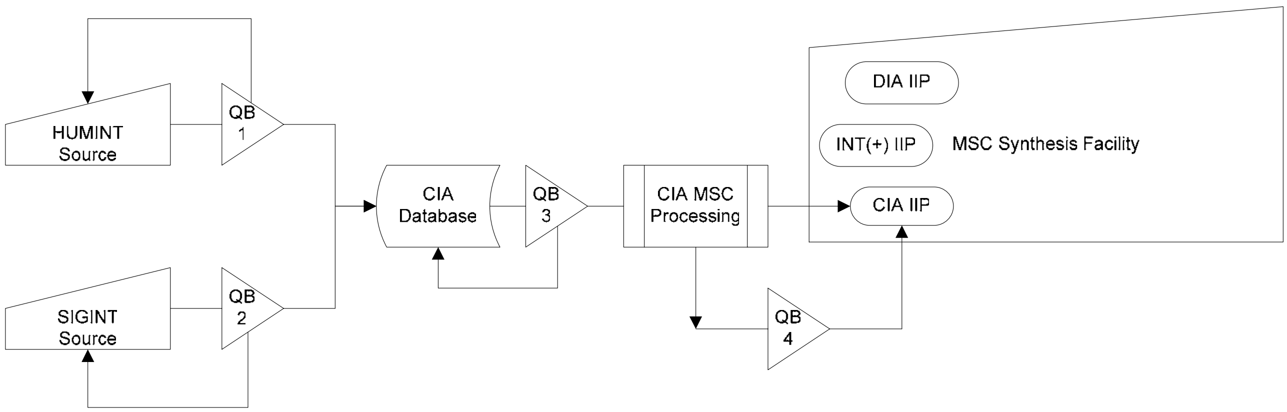

Figure 8. Intelligence agency analysis facility with quality blocks.

the data records. The CIA station personnel at the MSC, along with their specific instrumentation and computer equipment, comprise the CIA MSC Processing block. The output of their activities is an intermediate information product (IIP) that becomes part of an integrated intelligence resource stream used in the manufacturing of the MSC's information products delivered to the end user through the applications layer. QB4 is a feed forward quality control that is used to forecast fluctuations in critical quality criteria levels to the MSC Synthesis Facility personnel. This diagram consciously forces the CIA Analysis Facility managers to decide where quality blocks should be located, what type of control should the impose on the information product flow, what type of activities should constitute these controls, how are these activities to be performed and by whom, and so on.

If the activities that act on the information product in a processing block are sufficiently well-defined and simple, then quantitatively tracking changes in quality criteria levels could be accomplished via a straightforward calculus. For example, suppose that *y* represented the processing block's output value of currency of the information product, and it is the result of a comparison between the differences of two inputs: x_1 and x_2 at any time *t*. The quality effect of this processing block on currency would then be $f_q(x_1, x_2, t) = x_1(t) - x_2(t)$. However, when processing is complex, it may be necessary to substitute subjectively derived quality response functions for a calculus-based

analysis in order to track quality criteria changes. The issue of exactly how to measure the quality attributes as they relate to information products is still an open question.

During the design phase for an information manufacturing process the construction of the flow chart itself has value independent of any subsequent analysis. It forces an NCO organization to consciously position quality blocks in the flow, thereby at least illuminating high priority points in the production sequence where quality should be insured in some manner. These quality blocks provide controls necessary for information quality maintenance planning. Whether these controls are implemented using automated procedures, software applications, managerial intervention, or some other means is largely driven by the purpose of the information product and the nature of the organization within which manufacturing is going to take place.

6. Impact on Existing Theory

An information product manufacturing framework is extremely valuable to proper design and construction of high quality information products and the processes that form these products for use. At this point, however, it is important to note that there are no existing quantitative characterizations of quality criteria capable of being directly applied to this framework. Even those specifically created to facilitate discussion of quality criteria in the context of information superiority [23] are inadequate for the task, principally because their adopted framework and its relative context differ significantly from the framework developed in this study. The conditional representation that lies at the heart of their modeling approach is nearly identical to that used to capture uncertainty flows in sensor-to-shooter systems [7] whose focus is on elements of reliability as opposed to quality.

High quality information makes it easier to transform information into knowledge by helping to interpret and evaluate the information, by assisting in connecting to prior knowledge, and by facilitating the application of the information in new contexts.

One method of measuring the levels of information quality on a more aggregate level would be to assess the likelihood that the information would get turned into knowledge *a priori*, or to assess the percentage of information that does get turned into knowledge *a posteriori*. Assuming that the assemblage of an information product is guided by a single purpose originating from a single intent enables one to estimate these measures for each of the quality criteria by assessing the degree to which they correspond to that purpose. This is one promising avenue being investigated by the authors.

This manufacturing framework agrees with that of the NCOCF in that one must implicitly assume it is possible to describe the quality of information using a finite set of criteria grouped into meaningful

dimensions [2]. It diverges in the sense that it defines these criteria relative to a specific product. Survey instruments of the type used in support of the NCO case studies mentioned in this study and other recent analyses of NCO systems are recognized as the principle means of assessing the degree of adherence to such criteria when information is conceptualized in a general sense. Thus, while we advocate surveying end users to assess the subjective criteria related to service reliability, we consider this approach inappropriate for assessing the quality criteria levels of information products.

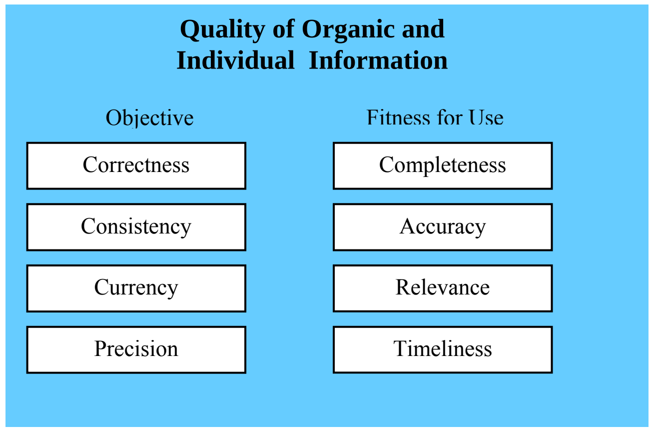

Figure 9. Eight quality criteria currently contained in NCOCF.

The eight criteria currently specified in the NCOCF are shown in Figure 9. Perry et al. [23] define each of the criteria as follows:

- Correctness – the degree to which information agrees with ground truth.
- Consistency – the extent to which information is in agreement with related or prior information
- Currency – the situation independent time for the C4ISR to produce and distribute a CROP
- Precision – the level of measurement detail in an information item
- Completeness – the degree to which information is free of gaps
- Accuracy – the appropriateness of the precision of information to a particular use
- Relevance – the proportion of information collected that is related to the task at hand
- Timeliness – the situation-dependent degree to which information is available when needed

The same study posited the belief that information quality, the inherent 'goodness' of information, is situation independent. This is an existential position consistent with viewing information in a general sense. We agree that information should be conceptualized as an entity apart from the technology that carries it, but are not willing to assign complete situational independence to its descriptive quality criteria, especially in the context of information product manufacturing.

While an information product can assume a vast array of forms, underlying all forms is a specific purpose that recognizes the information product is to be *used*. The arrangement of content and functions associated with the product (its design) is driven by this purpose. Purpose is a manifestation of intent and the information product, if properly manufactured, by extension is a physical manifestation of this same intent. Part of the process of validating or assessing the information quality, and reliability as we explain later, lies in an ability to start with the final information product and perform inference as to the actual intent given the

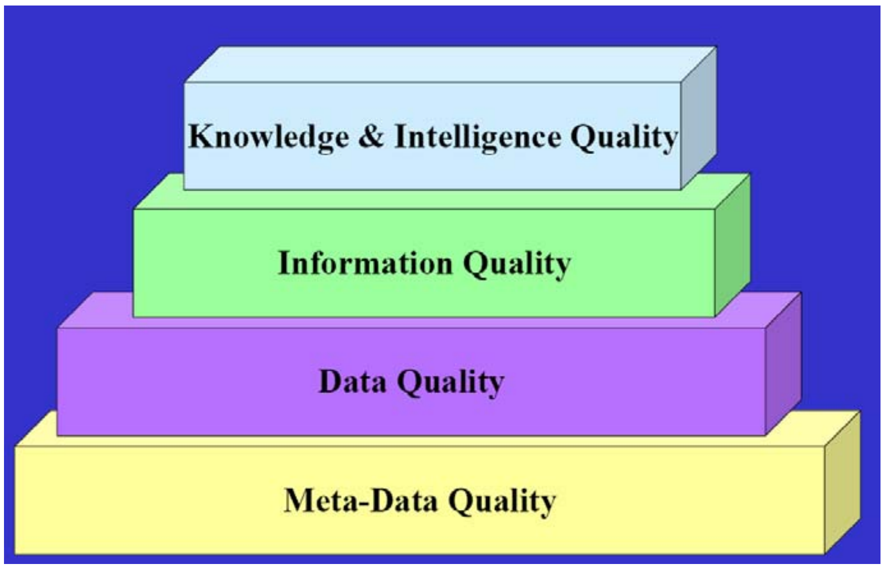

Figure 10. Layers of quality. (Iverson: *Meta-Information Quality*, ICIQ 2001)

evidence present in the product. This is a form of reverse engineering applied to an abstract notion of product.

In the commercial sector, information products in advertising are manufactured for the purpose of shaping consumer perception or to establish distinctive characteristics that set apart, or strategically "place," a product within its competitive landscape. Whether or not the product is actually purchased by a consumer is outside of the control of the information product manufacturers.

In a military context, a vast majority of information products are manufactured with the purpose of helping decision-makers perform accurate inference estimates concerning critical parameters of battlespace behavior. This purpose establishes relevancy against which quality characteristics can be meaningfully defined. When viewed through the lens of manufacturing information products, these criteria are most definitely situation dependent. Such a distinction would not be evident were it not for this approach.

Both this new perspective and the existing literature bears out that an amount of revision in the stated NCOCF criteria is required. Principally this is so because several of the current quality criteria

are too general to be of practical use in the design of information products.

Fundamentally, issues of quality exist on the four layers shown in Figure 10. The objective criteria of precision and correctness are recognized data quality issues that are principally the focus of information assurance efforts. For military operations, such as those documented in the NSWG-1 case study, precision translates into a user need to have sufficiently specified location data to facilitate operational targeting. This requirement is arguably a topical subset of accuracy, as explained in what follows.

The criterion of *timeliness* is actually an aggregate measure that bears further decomposition as is explained shortly. The criteria of *relevance* is generally unworkable as a criteria for information quality because it contains various types of pertinence that should be distinguished, not all of which are necessary to examine in the context of military NCO systems. Saraceciv [10] detailed five principle notions of relevance as they apply to information systems: system, topical, cognitive, situational, and motivational.

System relevance expresses the relation between a query and the resulting information objects. Direct assessment of system relevance is left to the end user and is based on the effectiveness of the received information objects for performing inference.

Topical relevance, which expresses the degree of "aboutness" contained in the information object, would appear to be automatic for most DSIN used by the military because systems exist for focused, mission-oriented functionality. Queries in this setting are topically relevant or they do not exist.

Cognitive relevance expresses the relation between the user's state of knowledge and the degree to which the information object fulfills the cognitive information need of that user. It follows that the degree to which the information informs the user appears to be a useful direct measurement of this criteria. Notice the user-centric nature for the assessment of this criterion.

Situational relevance expresses the relation between the situation, task or problem at-hand and the information retrieved from the system. One will note that this criterion is very closely aligned with topical relevance. The distinction between the two lies in its intent: this notion of relevance goes directly to the usefulness of the information object for decision making and reducing uncertainty related to the situation at-hand. In this sense, situational relevance is likely to be what was intended in the specification of the NCOCF criteria shown in Figure 2.

Lastly, and perhaps the most subjective of all five notions of relevance, there is *motivational* relevance. This notion of relevance expresses the relation between the intents, goals, and motivations of the user and the information retrieved from the system. The most common aspects of measurement in this regard are user satisfaction, user expressed success and the sense of accomplishment afforded or facilitated by the information object provided by the system.

A note on *trustworthiness* is also appropriate here. Although it is not contained in the current NCOCF criteria, it has been bantered about in discussion as one valuable measure of quality. As a subjective notion, it is interesting to consider, but as an objective criteria it is too high of a subjective abstraction to be of worth to systems designers. Trust of information products is attained by insuring that the appropriate levels of core objective quality criteria are met.

In all, one gets the sense of the complexity associated with including relevance as one criteria of information quality. The two notions of relevance that readily apply to military systems, cognitive and situational, both rely on user-based subjective assessments. It is for this reason that they should more

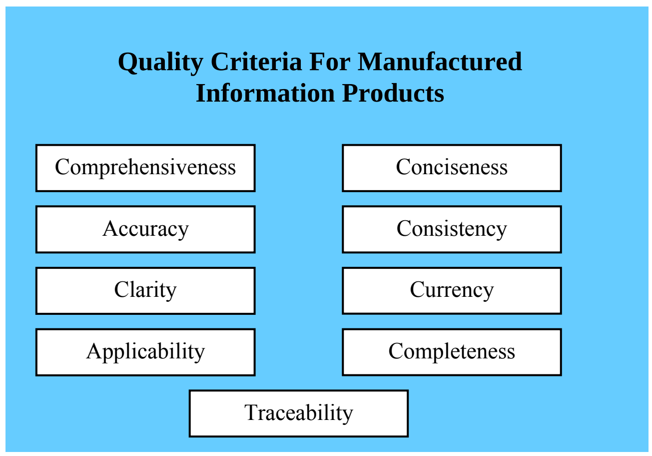

Figure 11. Information product manufacturing quality criteria for the NCOCF.

appropriately appear as supporting criteria for service reliability.

Of the 16 standard information quality criteria accepted in practice [2], we consider ten to be candidates for defining the principle quality criteria of information for NCO information systems.

The criterion known as *correctness* (Is the information free of distortion, bias, or error?) is properly a criterion of concern for information assurance, as is *security* (Is the information protected against loss or corruption?). We also exempt *interactivity* (Can the information process be adapted by the end user?), *accessibility* (Is there a continuous and unobstructed way to get to the information?), and *speed* (Can the infrastructure match the user's working pace?), and *convenience* to be elements of service reliability, a complementary study to this effort.

The criterion known as *timeliness* (Is the information processed and delivered rapidly without delays?) is best divided into two components: *currency*, which is part of the criteria we already address, and *volatility* (How quickly does the "risk-to-use" change? Aka: shelf-life of risk.). Because this second component is a direct measure of risk-to-use, which is the basis of our reliability construct, we consider it as part of reliability as opposed to quality.

Within an information product perspective, the nine remaining criteria shown in Figure 11 represent the span of quality characteristics appropriate for inclusion in some manner in the NCOCF. These criteria encompass elements of both dynamic and static information products.

- **Comprehensiveness**: is the scope of the information product adequate for its intended purpose?
    - **Example**: weather data for the purpose of determining the feasibility of attacking an objective at a specific date/time is bounded +/- three hours.
    - **Counter-example**: weather data includes areas, dates, and times not relevant to the mission.
- **Accuracy**: are the information product components precise enough or close enough to reality for its intended purpose?
    - **Example**: digital imagery in support of targeting ROE determination has enough resolution to read appropriate religious symbols on the structure.
    - **Counter-example**: resolution insufficient to distinguish markings.
- **Clarity**: is the information product understandable to the end user in each component presentation form employed during its lifecycle?
    - **Example**: critical logistic supply levels provided to the end user in graphical display that indicates warning levels at which the end user should take action.
    - **Counter-example**: critical logistic supply levels provided to the end user in extensive data tables.
- **Applicability**: can the information product be directly applied by the end user at its sequence deployment point or does it have to be further transformed by the user?
    - **Example**: target ground location for the purpose of scheduling indirect fires is transmitted to SEAL team via a hand-held device using GPS data within 1 meter.
    - **Counter-example**: target ground location is provided using UAV digital imagery that must be fused with map information by the user.
- **Conciseness**: is the information product to-the-point and devoid of unnecessary or distracting elements?
    - **Example**: situation report presented in bullet list or aggregated image form.
    - **Counter-example**: situation report presented in prose form with in-depth explanations of standard terms.
- **Consistency**: is the information product free of contradictions and convention breaks at any point in its lifecycle?

  - **Example**: each open window of a multiple window display used for estimating enemy situational awareness provides complementary information in a form previously used by the end user during training.
  - **Counter-example**: friendly situational awareness information presented in an unfamiliar format (e.g., UK Force use of FCBC2 in Iraq.).
- **Currency**: is the information up-to-date relative to its resource at each sequence deployment point in its lifecycle?
  - **Example**: SEAL teams displayed intelligence information exactly matches that in the DIA database at the MSC facility.
  - **Counter-example:** system limitations allow DIA intelligence updates to SEAL teams to occur on-the-hour.
- **Completeness**: are the product components and their functional elements present in accordance with the time sequencing of delivery to the end user?
  - **Example**: high resolution digital video feed not present during initial product release (low resolution at that point) but product is preset to begin streaming on-demand by end user when ROE determination will need to be made.
  - **Counter-example**: product incapable of switching to high resolution digital video feed when needed without complete re-manufacturing of the information product.
- **Traceability**: are the sources supporting the information product visible to the end user at points where this is needed?
  - **Example**: end user is capable of quickly determining the source of contradictory intelligence information for use in a ROE determination.
  - **Counter-example**: end user cannot resolve contradictory intelligence information back to origination source.

Notice that completeness is defined as the degree to which the information product content contains the intended manufacturing components and functions supporting its purpose. This definition moves the assessment metric away from a comparison with ground truth, which continuously evolves and is never assessable beyond estimation with uncertainty, to a tangible product whose design and content are under the control of the manufacturing system.

The last criterion is new to the NCOCF. Information should be traceable at some level by information managers. This concern arose in the CTF-50 case study as a critical, yet easily overlooked criterion needed to assess the quality of information provided by the Knowledge Web (KWeb).

One of the reported strengths of the KWeb application was the fact that many individual users had

the ability to post information without extensive centralized review. The system exchange of information evolved to contain a strong degree of self-correctiveness because information was traceable in two directions: from the source to the product and from the product to the source. This feature enabled users high in the command structure and low in the command structure to validate posted information as needed in real time. They had an option to put all information through an approval process prior to posting, but opted for this approach instead.

This is a lucid example of users evolving to take advantage of a natural feedback cycle in the system to perform the information maintenance task of validating postings rather than creating a separate organization

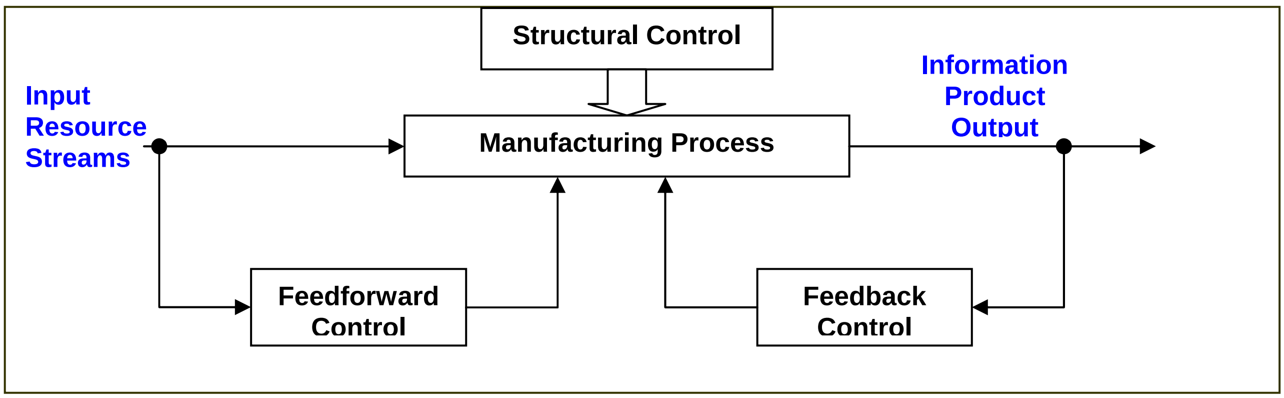

Figure 12. Major control elements for manufacturing information process.

to perform this task for the entire system. By leveraging both the system capability and the motivation among the user pool to be working with the highest quality information possible, the KWeb evolved to have a feature that went a long way towards establishing both trust and confidence in the user base.

7. Information Product Maintainability

Fundamental to the concepts of designing and manufacturing high quality and highly reliable information products is the associated belief that these valuable product characteristics can be maintained. Traditionally, one would conceptualize internal and external control features [24] to accomplish this. For military information product manufacturing for decision support, distinguishing between user processes and manufacturing system processes is more helpful for system designers.

The end user reliance on social network structures in the NSWG-1 case study as an adaptive work-around created to overcome some deficiency of the information product is an example of a user control process. A formalized capability of the MSC programmers to create tailored information products for the NSWG teams on demand is an example of a process intentionally imbedded into the

manufacturing process to maintain high quality.

Maintaining high levels of quality and reliability has in the past essentially meant building appropriate controls exclusively into the manufacturing process. In an earlier example, four quality blocks (QB) were inserted into the CIA Analysis Facility that focused solely on maintaining a high quality information product. To be complete, Figure 8 should also show the particular structural controls on the CIA MSC Processing activity itself that would target maintaining a high quality process as well.

It was this piece of the product life cycle that represented the dynamic element of the manufacturing chain because early information products tended to be predominantly static. Information products such as printed reports and books still align with this notion. When this type of product is released to an end user, the “Little-q” and “Little-r” instantiated levels of quality and reliability are assessed. Assuming that these levels are acceptable, the product is released to the consumer. Past this point, quality and reliability are a concern to the original manufacturer only so far as warranty obligations and re-manufacturing opportunities that extended the value-chain for these manufactured products are concerned.

Digital information products manufactured in support of military decision-making in an NCO environment however, are quite different. They quite likely have dynamic elements that possess imbedded functions directly connected to or dependent upon specific portions of the manufacturing process. Hence, it is useful to consider the maintainability of information products both prior to the initial release to the end user and during its life cycle.

There are three modes of control are appropriate to consider when addressing maintenance of information products: structural control, feed forward control, and feedback control. The positioning of these control elements in the flow of process is shown in Figure 12 and applied earlier in Figure 8.

Structural control is internal to the information product itself made possible by the interaction of a subset of the dynamic components of the product. This is a unique definition quite different from the traditional notion of structural controls, which are thought of a process controls. These dynamic components maintain an umbilical link to resource flows that are not severed upon deployment of the product to the user.

Structural controls do not rely upon regular monitoring of inputs and outputs. For the NSWF-1 case study, MSC personnel shift schedules, recruitment and assignment criteria for assigning personnel to the MSC, rotational assignments from CONUS MSC locations to in-theater operation sites, are examples of structural controls. In a more casual sense, these controls define the activities that are once (and more) removed from touching the manufacturing process, but are critical to maintaining a high quality or highly reliable information product.

Feed forward control relies upon regular monitoring of inputs to predict future variation in product quality or reliability in order that human intervention or triggered automated system action may be taken to prevent such degradation. An example of a feed forward control for COP quality would be the continuous monitoring of Dragon Eye UAV operational status (e.g., condition, fuel, camera status, etc.) that is providing a live digital imagery of a target. If the fuel levels of the on-site Dragon Eye UAV was anticipated to drop to the point that it could no longer logger onsite to support its information feed, a supplemental Dragon Eye UAV could be launched to insure that the COP quality in this dimension did not drop below acceptable levels during a critical time window. Feed forward control defines pro-activity with regards to information product manufacturing. Systems incorporating feed forward and/or structural controls only are referred to as open-loop systems.

Feedback control relies upon regular monitoring of outputs to assess deviations in product quality or reliability which indicate the need for corrective action to restore or adjust the product to its desired state. Systems incorporating this form of control are referred to as closed-loop systems.

Our interest in maintainability with respect to information products is several-fold. First, constructing a framework for identifying information quality maintenance locations in the flow of intermediate information products within the manufacturing process would enable systems designers to imbed product and process oversight that would contribute to the requirement of adaptability identified earlier.

Second, it would enable information managers to have focused activities at different stages of the product's life cycle. In addition to creating efficiency with respect to effort, this would enable managers to identify the critical skills needed by maintenance personnel, thereby contributing to structural controls necessary to insure the long term health of the manufacturing facility itself.

Ballou's concept of positioning quality blocks does not include feedback or feed forward controls. He envisions that blocks would be positioned to interrupt the flow of information, fix the deficiency, and allow the product to proceed only upon restoration or achievement of an acceptable Little-q quality threshold. While acceptable for static information products that do not evolve their quality criteria as we propose, dynamic products require dynamic feed controls in-place to properly maintain information product quality. These controls can be positioned in the manufacturing process to augment rather than interrupt the flow of information products to an end user.

7.1 The Information Sharing NCW Tenet, NSWG-1 Case Study

Information sharing in general does not necessarily enhance the quality of information products. In the manufacturing framework, quality is an intrinsic characteristic of an information product that is intentionally designed and controlled throughout its life cycle. It is directly dependent upon the

individual components comprising the product, their collective representation, and the functions they perform for the end user over time. Information sharing is one part of a process that can lead to improved information quality, but only in a system that has carefully designed and deployed product manufacturing processes with empowered information quality managers having access and authority to revise, update, refresh, repair, or replace components of the information product. Otherwise it is no more than the fortune alignment of people and activities touching the product through information sharing, the end result being an observed increase in product quality.

The NCW tenet concerning information sharing tacitly assumes these critical requirements are present in successful system implementations. We conjecture that the reason it is not explicitly stated as such is that the generic concept of information currently held is insufficient to identify this shortcoming without the concept of information product manufacturing. For the NSWG-1 case study, observers surmised that

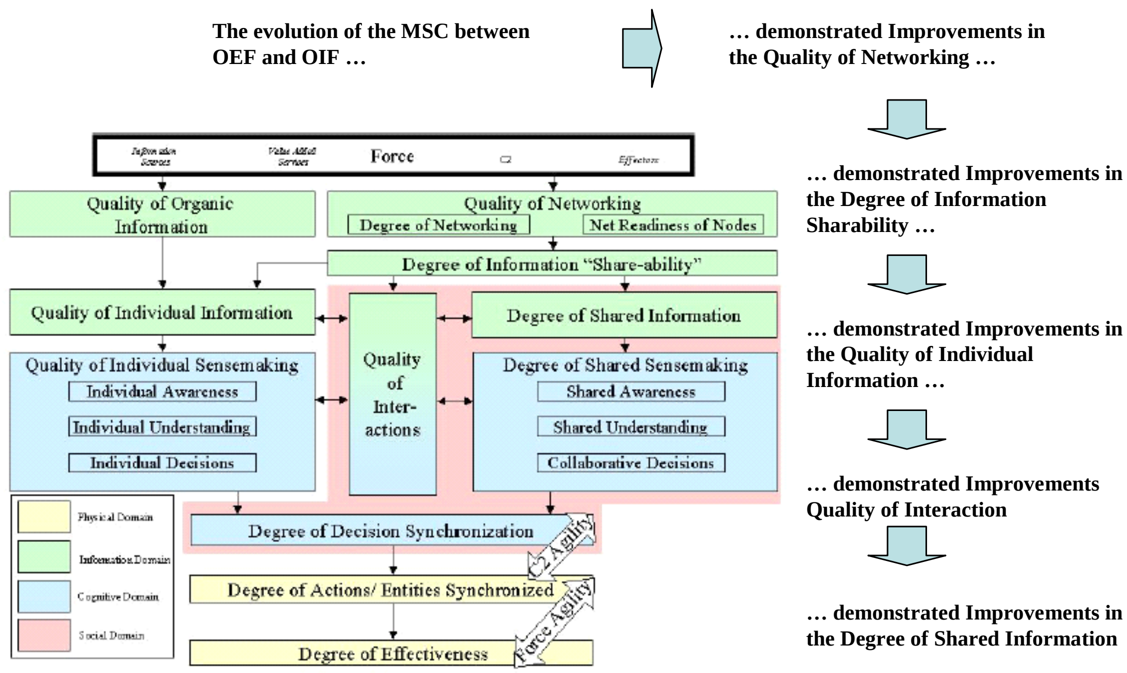

Figure 13. Observed NCW effects on information quality. (Source: Booz Allen Hamilton [30]).

"improvements in the degree of information shareability led to increases in information quality" (Figure 13).

That the "quality of information increased" during the MSC transition period from OEF to OIF is by now clearly too abstract of an observation to be actionable. That it directly followed from improving the ability to share information, which is almost exclusively a hardware and software issue, is doubtful. More likely is the case that many of the improvements and enhancements in the

information product manufacturing system were in fact observed but misdiagnosed. Again, we believe that had this information manufacturing framework been adopted and in-place prior to the case study and the language of manufacturing been available to them, then the actual story would have read more as shown in Figure 14.

Information sharing occurring via a COP in support of decision-making absolutely enhances operational collaboration across dissimilar units, as long as the COP was properly designed, manufactured and reliably delivered through the applications interface to the end user. This is one of the synergistic effects NCO should foster and develop. Collaboration is an active process in which parties involved commit to align effort under a unified purpose or intent. This unified purpose or intent is consistent with what Perry et al. [23] refer to as establishing common ground among collaborators, a critical determinant of success.

Information sharing in support of collaboration assumes that competent rational decision makers will exploit such information products when they receive them to the best of their abilities within the limits of the resources they control. When this occurs, collaboration is a success. When it does not happen, collaboration has failed. Information sharing can take place regardless of the end state.

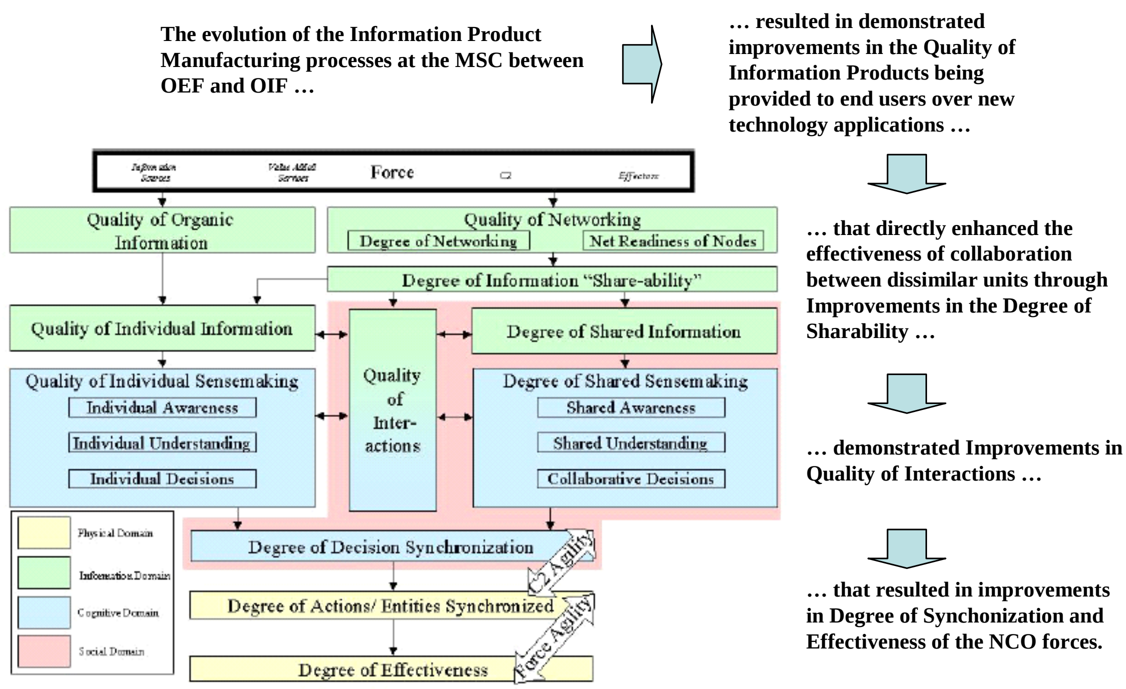

Figure 14. Observed NSWG-1 NCO effects from information manufacturing perspective.

With regards to the NSWG-1 case study, there are a host of observations and questions arising from adopting an information product manufacturing perspective that remain unaddressed. A select number

of them are briefly listed in what follows.

- "Leveraging reachback support at the MSC was a source of success."
  - What specifically happened to the information products being provided to the SEAL teams?
- "70 – 75% reduction in the forward footprint"
  - What specific personnel and units were shifted?
  - What skill sets did this represent in the context of manufacturing?
- "The MSC was able to gather all information, tailor it to the fleet…"
  - The system had flexible manufacturing points that could rapidly adapt the form and content of the information product to the evolving end user's needs rather than imposing this requirement on the user themselves to perform. That is, the end user did not have to develop "work-arounds" (see earlier diagnostic).
- "The MSC was a conduit…"
  - The MSC was a Synthesis Facility within the information manufacturing system.
- "Increased quality information available earlier in the planning process…"
  - This is actually a service reliability issue as opposed to an information product quality concern. However, the observation underscores the need to align a schedule of Little-q quality level product deliveries to the end user according to their needs.
- "The hallmark of SOF is that they are always open to change and out-of-the-box thinking…"
  - The observation pertains to user characteristics related to adaptability but does not necessarily relate to the structure and content of information products they require.
- "In theater personnel with operational knowledge of the MSC…"
  - This exactly parallels the benefits of having organizational managers who have progressed in their careers having spent quality time as part of the manufacturing labor force. So long as the major structural organization and processes of the facility remain reasonably consistent with their experience, they can effectively translate their knowledge of supply resources, manufacturing capability, and best practices of process execution into an advantage elsewhere in the organization. They are also imbued with a cache of influence recognized by those remaining in the manufacturing facility. However, had the organization at the MSC changed, the resident skill sets changed, the manufacturing processes changed during the period from OEF to OIF, the likelihood that this observation would have enhanced

NCO would be extremely small.

- "During OEF, the MSC command relationships were ad hoc and could not generate RFI's to the intelligence community…"
    - Formalized supplier relationships did not exist, leaving the MSC to compete for supply as a "walk in" customer. Sporadic supply availability translates directly to uncertain product availability to the end user. Service reliability suffers dramatically (and nonlinearly), decreasing the confidence in the end user that the product will be present when needed. In this situation, strong hierarchical organizations such as military units can at best impose a cautious dependency on the part of the end user. This is an important distinction to understand: ***the risk-to-use has not changed (information reliability), the quality of the product has not changed (information quality), but the ability of the system to furnish the product to the end user has (service reliability).*** This precisely illustrates the usefulness of decomposing an NCO system into three major focus areas as we have done.

On the 1999 mission capabilities to support new objectives:

- "Collocate intelligence and operations personnel that understood the intrinsic and idiosyncratic needs of NSW operators in any of their various missions, and who could provide the kind of specific information that the Joint Intelligence Centers provided."
    - Build an adaptable, capable information manufacturing process with high service reliability to the end user.
- "Develop liaisons with national intelligence agencies."
    - Establish formal links to resource suppliers relevant to the specific information products being manufactured.
- "Centralize blue-force monitoring via "black boxes" that deployed NSW forces would carry, and which would, via the MSC, all direct inject of NSW positions to the COP."
    - Establish a resource supply link with forward elements to feed a dynamic component of the information product.
- "Fuse operations and intelligence, located in the same physical space in San Diego, to provide the same staff functions without a large deployed footprint."
    - Take advantage of the location-independent manufacturing elements and shift them to appropriate locations in the supply chain that minimize the costs associated with operating these elements.

8. A Concept of Information Product Reliability

Every information product consists of static and dynamic components linked together by the single purpose motivating its manufacturing. These components, both in presence and function, have parallel and sequential dependency relationships that can degrade, fail, be refreshed, and can be replaced. In this sense, the notion of information product reliability is relevant. Exactly how to define these relationships and what underlying mathematical functions describe their behavior over time is our ongoing concern.

In this vein, we believe it prudent to begin to construct a precise foundation for reliability theory of an information product from first principles rather than simply adopting attractive metaphors where we see opportunity. This section introduces our initial thinking on the matter with regards to a specific information product being manufactured today: digital common operating pictures (COP) of the battlespace used to enhance situational awareness of friendly ground force commanders (and others).

Having previously investigated information reliability structures for sensor systems [7], we do not concur with information reliability characterizations based simply upon propagated uncertainty tracking. Although this dimension influences what we would traditionally describe when discussing stochastic measures of reliability, focusing on this aspect in the context of manufacturing information products appears to be of little use. It represents an aspect of the information manufacturing system well outside the span-of-control of product design and manufacturing, and more in the domain of information assurance and network administrators (thinking in a digital sense).

This earlier probabilistic structure [7] lines up with Huang's [6] systematic approach, which focused on how information may become deficient during the information production process though the influences of uncertainty generation. At the heart of this earlier approach is a presumption that there exists a perfect data state against which any product could be compared. Herein lies the difficulty much in the same manner that caused us to discount the usefulness of information quality criteria being compared to ground truth. In fact, Eppler [2] notes that few research strategies have adopted this deductive-analytic or ontological approach in which real-life states are compared to represented data states for many of the same reasons we posit.

The fundamental characterization of information reliability we are exploring is based on a "risk-to-use" criterion at a time when an estimation or decision must be made that is directly dependent upon the information product in order to do so. A military information product's manufacturing design is centered on a comprehensive understanding of how the product is going to be used: its *purpose*. This is consistent with the information product manufacturing framework we present herein. Hence, we

believe that since this purpose binds the components of the information product, it therefore is the most logical construct upon which to develop a reliability theory. Furthermore, since we assume that purpose follows intent, each of the information product's components supporting this intent is, in effect, providing evidential support for inference estimation, particularly for the case of achieving situational awareness in the face of un-resolvable uncertainty. A reasonable challenge is imposed because of the static and dynamic nature we imbue to information products.

We conjecture that exposure to some subset of environmental factors affects the degree of support to purpose that an aggregated information product provides. Individual components can fail to the extent that their support of purpose diminishes. Towards this end, each of the components has an inherent refresh rate (dr/dt) that determines the extent of content refreshing and the time interval within which such refreshing must take place in order to maintain a reliable product. These must also be aligned to the Little-q deployment schedule associated with the product.

Past a threshold level of minimum support for purpose, the component fails to support the purpose to which the product was designed. It must then either be replaced, discarded as a component altogether, or be refreshed (which is equivalent to content re-manufacturing, the idea behind updating). When a sufficient number of components fail, mutual evidential support for the underlying purpose of the product is no longer present and the information product as a whole fails. Figure 3 illustrates an example of an information product in which each of the designated areas contains a different presentation format, content, and is either static or dynamic.

It is possible that reliability in this sense could be inextricably linked to the end user, which is why investigating this idea is related to active/passive user interaction with digital displays currently being investigated by the Department of Behavioral Sciences at USMA. In this context, each product component has a required react time (Δt) associated with it that captures a sense of the component's importance to the purpose. Components with small Δt are of high importance, those with large Δt are less important. In fact, the relationship of a component to the product's purpose in this manner defines a prioritized dependency relationship that could drive maintenance and security planning as well.

The failure of individual components can be described by either deterministic models driven by factors under the control of product manufacturers, or stochastic models driven by factors not under the control of product manufacturers. The latter case illustrates an interesting dimension to information product reliability: that it can fail partially or completely through no fault of its own. And this characteristic sets it distinctly apart from other applications of reliability.

For the case of stochastic models, failure distribution $f(*)$ must be specified and validated. Based on the component failure distributions and their associated relevancy refresh rates, a risk-to-use

measure could be developed akin to a hazard rate function. The risk-to-use measure dynamically changes with time, increasing and decreasing as maintenance actions take place and the content and functions of the product are updated.

One particular purpose for information products is to support decision makers' estimates concerning OPFOR operational states or on insurgent effects states. This is support for inference. If reliability degraded, the product or its components ability to support inference degrades. That is, given that H_0 is false, its ability to support H_1 with tangible evidence presented in the information product diminishes. One could in this case, consider the mapping from evidence to inference to have failed, which would go to assessing the reliability of the mapping function itself, or that a single component (or more than one) has failed.

We suspect that our notion of information reliability will be susceptible to modeling using a quasi-renewal process based on the distribution of inferential support of purpose conforming to an appropriate functional distribution (See Nachlas et al. 2004). How exactly to translate this and what qualities must be present in the underlying distribution have yet to be answered.

9. The Kiviat Diagram as an Information Product

Kiviat diagrams have been used for many years in computer performance evaluation [46]. In general, a Kiviat diagram is constructed for the purpose of enabling the user to make comparative assessments cross a host of representative dimensions which, in aggregate, represent a holistic evaluation of the system of interest. Each value of each measure is displayed on its own individual axis, plotted as a point. By connecting the points across each axis, a pattern is formed.

Consistent with this purpose, the component elements presented on each of the axes are mutually supporting. When the display is static, the data represents the results of assessment "as is." A single webline is used to connect the points. When the display is intentionally dynamic, attempting to enable the user to perform a comparative estimate such as "before and after", then multiple weblines are typically used, as in Figure 12.

We have one concern with the use of Kiviat diagrams in the context of NCO case studies that we address, that being scale and unit differences inducing a distorted "Δ effect." This concern arises because of our sensitivity to the role of a Kiviat diagram as an information product when it is delivered to an end user.

A. Scale and unit differences: the Δ effect

In this dynamic context, maintaining normalized axes across the dimensions is critical because the marginal differences, say, between two system's performance criteria, expressed in percentages of differences between one webline (before) and another (after), are both meaningful and relevant. When the axes have different scales and units, a reader can easily be misled into over- or underestimating the comparative differences between systems.

Barzilai ([50], [51], [52]) was one of the earliest researchers to bring this concern to light. At the time, his concern centered on the lack of consistency and apparent reversibility of results when applying an Analytical Hierarchy Process (AHP) to compare multiple criteria. He demonstrated mathematically that the principle reason for this was exactly the same as we mention here: scale mismatch and scale inadequacy.

Unlike Barzilai's concern over reversibility in AHP, our concern is that although no explicit mathematical combination of scales is being performed, the user is in fact performing a didactic functional transformation by forming opinions and drawing conclusions from the diagram. Without explicit statements concerning the limitations of what the display is attempting to communicate in comparison between systems, a reader could easily misinterpret limitations as to what these should

be, a reader could easily come to over or under estimate the impact of system differences.

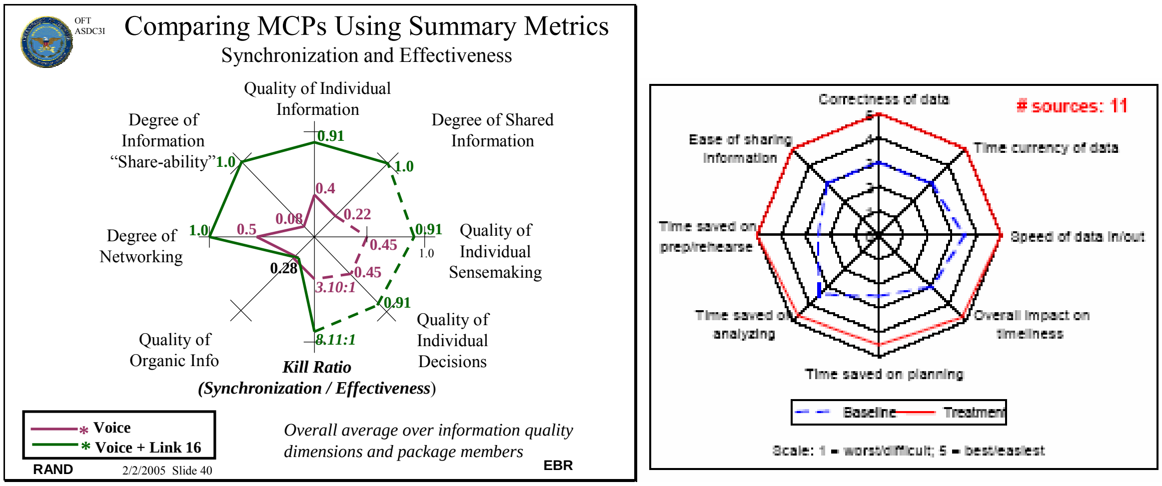

Figure 15. Comparative information NCO Kiviat diagrams.

Using a Kiviat diagram to show a rollup perspective of static (single) category performance differences is not advisable unless the scales used on the individual axes are identical. The Kiviat diagram on the right of Figure 15 is one such use that is proper. In this case, subjective data supporting the eight categories of performance were gathered using survey methods. All eight axes scales rely on a single Likert scale whose values run between 1 and 5. The area between weblines then properly communicates the relative proportional differences in system performance.

One must still be careful to not misuse numerical data that results from Likert scales, the classic example would be to take the average Likert score for, say, Degree of data input, and use it to estimate some 'population mean' judgment concerning the same. This is especially a concern when one transforms subjective data onto a continuous interval scale, as in the Kiviat diagram on the left in Figure 15.

10. Final Note: In Defense of Generalizing Case Study Results to Force Transformation Theory

It is important to note the logical basis for generalizing applications of information quality and service reliability concepts to the NCOCF using the case studies as the basis of application and analysis. Almost without exception, each of the various case studies adds caveat addressing the strength of evidence in support of transformation lessons to wit: the small size of the sample renders the evidence statistically weak.

We note that this is not the case in general, and that the intended inferential use of the evidence resulting from interviews, surveys, and direct observation sufficiently justifies its purpose. The basis for this position

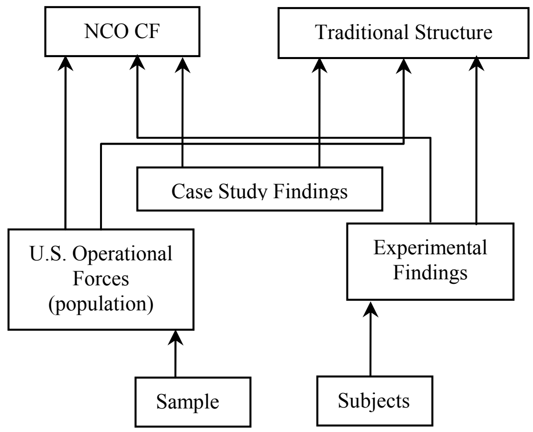

Figure 16. Yin's (1994) concept of inferential generalization.

lies in the distinction between the strength and appropriate use of observational studies versus controlled studies.

The defense of using single or multiple case studies (in any event small sample from a statistical sense) is laid out in Lee and Baskerville [7], consistent with Yin [8]. Figure 16 shows Yin's conceptualization applied to the NCOCF case study research effort. The upshot of their position is that statistical inference from a sample to a population is a type of inductive generalization that cannot be improved by increasing sample size, a position consistent with Hume's Truism [12]. We agree.

Increasing sample size increases the reliability of the statistical estimate because of strengthening the underlying mathematical assumptions upon which the estimation procedure relies. When this is possible, the statistical estimate validly deduces to an expectation of consistent results on other identically structured random samples of the population, but not to generalizing these to the population at large. In simple terms, while increasing the sample size improves the reliability of a population parameter estimate, it does nothing to either strengthen or detract from the inference itself.

Moreover, specific research results addressing a comparison between nonrandom sample based experiments and random sample based experiments ([13], [14], [15], [16], [17]) directly support this position.

In both the CTF-50 and Stryker case studies, analysts emplaced a caveat on their findings of a concern that their surveys were applied to a small, but representative cross section of the NCO

information network users. In the opinion of these authors, such a caveat is both unnecessary and unfounded in light of the above. In both cases, survey data were not gathered to support inference to a larger population of users nor to extrapolate to a larger population of NCO systems across the services, the concern of statistics. Inference was being made to the theory of NCO, upon which the results, even as a small sample, stand on firm ground.

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This study introduces a pragmatic methodology for examining the effectiveness of decision support information systems for Network Centric Operations based on the concept of manufacturing information products. We first develop the definitions and framework for this manufacturing environment, establishing a connection with previous research and extending it into a value-focused domain. We then apply this framework to elements extracted from two recent case studies involving US Forces focused on validating the tenets of Network Centric Warfare, illustrating its unique ability to identify systems level concerns overlooked previously. Lastly, we extend our concern for the reliability of information products, showing how this both complements a quality analysis and, taken together, prescribes a methodology for creating effective information-based decision support tools.

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